MCAT Institute
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HIGH SPEED TRANSITION
PREDICTION

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MCAT Institute
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San Jose, CA 95127

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Introduction:

The main objective of this work period was to develop, acquire and apply state-of-the-art tools for the prediction of transition at high speeds at NASA Ames. Although various stability codes as well as basic state codes were acquired, the development of a new PSE (Parabolized Stability Equation) code was minimal. The time that was initially allocated for development was used on other tasks, in particular for the Leading Edge Suction problem, in acquiring proficiency in various graphics tools, and in applying these tools to evaluate various Navier-Stokes and Euler solutions.

The secondary objective of this work period was to attend the Transition and Turbulence Workshop at NASA Langley in July and August, 1991. A report on the Workshop follows.

Transition and Turbulence Workshop

From July 8, 1991 to August 2, 1991, the author participated in The Transition and Turbulence Workshop at NASA Langley. The purpose of the Workshop was to bring together, at the same location, many of the researchers, both domestic and foreign, in stability, transition and turbulence so that familiarity with current efforts in these areas could be gained, and so that ideas could be shared among the various researchers. The Workshop was jointly sponsored by ICASE (Institute for Computer Applications in Science and Engineering) and NASA Langley, and was similar to the Instability and Transition Workshop, also jointly sponsored by ICASE and NASA Langley, and also held at NASA Langley two years earlier.

The Workshop consisted of various seminars, presentations and demonstrations. The attendees were divided into special interest groups, with the author having been placed in the Advanced Stability Group, the Group Leader being Mujeeb R. Malik of the High Technology Corporation of Hampton, Virginia. A list of the various groups as well as the researchers involved is given in Appendix A to

illustrate the wide scope of the Workshop and to identify some of the participants in the Workshop.

A significant change from the original workshop was that turbulence modeling and turbulence theory were now included as topics. This was done in an attempt to broaden the scope of the Workshop as well as to introduce another category of researchers to the stability and transition researchers that were in attendance earlier, and to the newer people who had not attended earlier.

Stability and transition researchers were seen to fall into several categories: those who did numerics, those who did analysis, and those who did experiments. Numerical research consists of DNS (Direct Numerical Simulation of the Navier-Stokes equations); linear stability theory (compressible and incompressible), with the use of the e^N method for the prediction of transition; the Parabolized Stability Equation method (PSE) for the prediction of transition; and the numerical study of receptivity.

For the purposes of interest here, analysis can be said to consist of solving simplified governing equations by various analytical methods, such as asymptotic methods, or by use of very meager computer resources. From the composition of the various groups at the Workshop, it can be seen that analytical methods are generally more popular in Great Britain than they are in the US, possibly due to historical factors and the lack of computer resources.

Experimenters at the Workshop were mostly concerned with subsonic flows, and a number of demonstrations were provided, among which were a hot-wire experiment to probe the boundary layer on a rotating disc, a hot-wire rake to map a free shear layer behind a cylinder, and the use of heating strips on a flat plate to control instability waves and consequent transition. A highpoint of the demonstrations was the opportunity to observe the rather noisy "quiet" supersonic pilot tunnel in operation.

Researchers who were involved in compressible linear stability theory, the author's main interest, were relatively few, but there were some new players. M. Simen[1] of the DLR, derived the compressible stability equations with curvature to attempt to resolve some long-standing controversies between linear stability theory and experiments, particularly those of Stetson[2] and Kendall[3]. Numerical

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results by Mack[4] and Gasperas[5] had shown good agreement between calculated and measured most amplified frequencies in a hypersonic boundary layer on a sharp cone. Agreement between calculated and measured amplitudes was less favorable. Using his new code, Simen was able to show excellent agreement between calculation and measurement of both most amplified frequencies and also amplitudes. However, stable regions between the first and second modes were also predicted, a situation not in evidence from experiments or from previous calculations. Details are given in a recent publication by Simen[1], where it is suggested that the discrepancies arise from using different basic states (thin-layer Navier-Stokes vs. similarity solutions, etc.). Additional work still is required to definitively resolve the issue.

PSE methods for the prediction of transition location were the subject of research by M. Malik and C.-L. Chang, both of High Technology Corporation, and F. Bertolotti, currently at ICASE. In a seminar dealing with the prediction of transition in high speed flows, Malik presented some results comparing compressible linear stability theory with the PSE method. Good agreement between the two methods is found where the two approaches are valid (i.e.. the initial, linear region), with deviations increasing towards the nonlinear region. The results are found in a paper by Malik and Chang[6]. This indicates that PSE methods, when they become more routine in application, may supplant the e^N method with results that are easier and cheaper, as well as hopefully more accurate, to obtain computationally than e^N predictions. Also, the final nonlinear regions before the breakdown to turbulence may be easier to elucidate than the current computationally exhaustive DNS methods.

A highlight which occurred during the time of the Workshop was the Eli Reshotko Symposium, given in honor of the 60th birthday of Eli Reshotko. Although his birthday occurred the previous year, and although the Symposium would more logically have taken place under the auspices of NASA Lewis, approximately seventeen researchers, many of them former students of Reshotko, presented talks on their various specialties. An Agenda for the Symposium is included in Appendix B because attendance at the Symposium was by invitation only, and because most of the presentation were videotaped (and are consequently available) by the author of this report.

Among the presenters, Th. Herbert of DynaFlow, Inc., one of the originators of the PSE method, was scheduled to give a presentation of how PSE methods were used in predicting transition. Because he was unable to participate, F. Bertolotti, a student of Th. Herbert and one of the original researchers on the PSE method, took his place, presenting an outline of the method as well as some results for flat plate boundary layers.

The author felt that last year's Workshop had a different viewpoint from the first one that took place in 1989. Fewer researchers from foreign countries attended, and the summary talks, given during a week of that earlier Workshop by virtually all of the most renowned people in the field (such as Stetson, Kendall, Arnal, Kleiser, Spalart, etc.) were lacking, since most did not attend this particular Workshop. However, for those who attended, the opportunity was splendid for further research into their own specialties, having interactions with new researchers, and learning about the approaches that others take to solve the transition problem, approaches that may prove useful in the future. And the opportunity to acquaint oneself on a personal basis with many of those who will be active in the field for many years to come was an invaluable experience, one that was, gratefully, not missed.

After the Workshop, the author took the next two months off as leave without pay to deal with personal business matters.

NASA Ames

During the period October, 1991 to June, 1992, the primary activities were as follows:

(1) familiarization with the various computer systems at NASA Ames

As a new employee, initial activities were the utilization of the Fluid Mechanics Laboratory (FML) system. Experience in the use of Eagle and Columbia was also acquired.

(2) familiarization with various stability and transition codes as well as graphics codes

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The COSAL code of M. R. Malik[7], PLOT3D, GAS and PIXEDIT were used so that they would become routine tools for future utilization.

The Navier-Stokes calculations by J. Garcia in support of the High Speed Civilian Transport (HSCT) program of the blunt Royal Aircraft Establishment (RAE) supersonic wing (a NACA 64A010 airfoil) were viewed using PLOT3D. The calculations by Garcia were for an airfoil of 70 degrees sweep, Mach 1.5 and zero angle of attack. Some example graphics for the RAE wing are shown in the next two figures.

Figure 1.) is a plot of the pressure coefficient on the surface of the wing constructed using PLOT3D, GAS and PIXEDIT. Figure 2.) is a plot of the same wing, with the pressure distribution given only at midspan. The pressure distribution has a ribbon-like appearance because two spanwise stations are plotted to make the colors appear more distinct.

In addition, the Navier-Stokes calculations by G. Klopfer of a 64A010 airfoil at various sweeps were evaluated using the same utilities, and some example plots are given in the next two figures.

Figure 3.) is a plot of the NACA 64A010 airfoil, with an aspect ratio of 3 to 1 for four sweep angles, ranging from zero to 70 degrees. The calculations were made in support of the supersonic "quiet" tunnel development at the FML. Only the geometry is given in this figure.

Figure 4.) shows the results of plotting the calculations by G. Klopfer for the pressure coefficient onto the various airfoils. The distinctions in the values of pressure coefficient are immediately apparent, and were used to evaluate the quality of the calculations.

(3)   the acquisition of outside codes for future use at the FML

TRANSPAK, a PC based code for the calculation of transition location on flat plates and cones based on compressible linear

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stability theory as well as the N-factor method, written by Gasperas, was acquired from AEDC in Tennessee, and adapted for use on the FML system. This code is presently limited to a narrow range of hypersonic Mach numbers, but can be extended if desired.

Other transition and stability codes, also written by Gasperas (similar to COMPOSE[8]) were acquired as well including various 2D temporal and spatial codes applicable to flat plates and cones.

A 3-D boundary layer code written by J. E. Harris of NASA Langley and V. Iyer of Vigyan Research Associates in Hampton, Virginia was acquired (ref: NASA Contractor Report 4269, January 1990). The code is fourth-order accurate and applicable to compressible flow on wings and fuselages. The code is to be used in an attempt to overcome the limitations inherent in the Kaups and Cebeci code (which uses the conical flow assumption) currently coupled to the COSAL stability code. In addition, the code will provide capability for the calculation of attachment line boundary layers. The code was compiled, and test cases were run to assure proper functioning.

Other versions of the 3-D boundary layer code are to be acquired as soon as they are completed by V. Iyer. Among these are a 3-D code for a tapered swept wing in orthogonal coordinates and a 3-D code for a general swept wing. It is expected that these codes will be available in the next several months. In addition, a Navier-Stokes to COSAL interface will also be made available when ready.

A code based on the PSE method was obtained from Th. Herbert of DynaFlow, Inc. under an SBIR. This is a 2D compressible code which will be used to compare with calculations using linear stability codes to gain familiarity with PSE methods. The code will also be evaluated for possible extensions, and may be used as a reference for PSE codes which are later developed at Ames.

(4)   various stability and transition support calculations

The COSAL code was used for crossflow and Tollmien-Schlichting (TS) calculations of transition location on the F16XL Ship

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1 wing-glove. These calculations were in support of the High Speed Research Program (HSRP), and have been performed primarily to date by L. King of the FML. All passive glove calculations to date have been performed by L. King.

For the active glove, crossflow calculations were desired for Mach numbers between 1.6 and 1.7, at altitudes of 44K and 55K feet, and were performed for the lower Mach number case, primarily by L. King. Crossflow calculations were performed by Gasperas as a check, and to gain experience with COSAL. TS calculations were performed by Gasperas, and showed no important modes.

For the high altitude case, it was found that the pressure distribution supplied from outside FML using a Navier-Stokes code was incorrect. This resulted in a reevaluation of the Navier-Stokes results for both suction cases, and has necessitated the complete recalculation of both suction cases. The mean flow for the Mach 1.6 case has just recently been completed and stability and transition calculations are in progress.

(5)   attendance at professional meetings

The meeting in Scottsdale, Arizona, November 24-27, 1991, of the Fluid Dynamics Division of the American Physical Society was attended, as was the 30th Aerospace Science Meeting and Exhibit of the AIAA in Reno, Nevada, January 6-9, 1992. A short presentation was made to the U.S. Transition Study Group, which held its sessions during the Aerospace Science Meeting. Participation at such national and specialist meetings is considered vital if a leading edge knowledge of both stability and transition technology and techniques, as well as the personnel who are active in these areas, is to be maintained.

REFERENCES

1.) Simen, M., and Dallmann, U. "On the Instability of Hypersonic Flow Past a Pointed Cone--Comparison of Theoretical and Experimental Results at Mach 8", Forschungsbericht DLR-FB 92-02, 1992.

2.) Stetson, K. F., Thompson, E. R., Donaldson, J. C., and Siler, L. G., "Laminar Boundary Layer Stability Experiments on a Cone at Mach 8. Part 1: Sharp Cone", AIAA-83-1761, presented at the AIAA 16th Fluid and Plasma Dynamics Conference, Danvers, Massachusetts, July,1983.

3.) Kendall, J. M., "Wind Tunnel Experiments Relating to Supersonic and Hypersonic Boundary-Layer Transition", AIAA Journal, Vol. 13, No. 3, March 1975.

4.) Mack, L. M., "Linear Stability Theory and the Problem of Supersonic Boundary-Layer Transition", AIAA Journal, Vol. 13, No. 3, March, 1975.

5.) Gasperas, G., "The Stability of the Compressible Boundary Layer on a Sharp Cone at Zero Angle of Attack", AIAA-87-0494, presented at the AIAA 25th Aerospace Sciences Meeting, January, 1987.

6.) Chang, C.-L. and Malik, M. R., "Compressible Stability of Growing Boundary Layers Using Parabolized Stability Equations", AIAA-91-1636, presented at the AIAA 22nd Fluid Dynamics, Plasma Dynamics & Lasers Conference, June, 1991.

7.) Malik, M. R., "COSAL--A black-box compressible stability analysis code for transition prediction in three-dimensional boundary layers", NASA Contractor Report 165925, May, 1982.

8.) Gasperas, G., "COMPOSE: A Program for the Solution of the Compressible Linearized Two-Dimensional Boundary-Layer Stability Equations, User's Manual", AEDC-TR-86-37, 1986.

Figure 1.)

NACA 64A010 AIRFOIL

VARIOUS SWEEP ANGLES, CONSTANT ASPECT RATIO

NACA 64A010

ASPECT RATIO = 3:1

25 DEGREES SWEEP

70 DEGREES SWEEP

0 DEGREES SWEEP

53 DEGREES SWEEP

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Fluid Mechanics Laboratory
G.Klopfer, G.Gasperas, S.Davis

FIGURE 2.)

NACA 64A010 AIRFOIL

MACH 1.5, ASPECT RATIO 3:1, ALPHA = 0

VARIOUS SWEEP ANGLES

PRESSURE COEFFICIENT

1 1

NACA 64A010

MACH 1.5   VISCOUS SOLUTION   ASPECT RATIO = 3:1

PRESSURE COEFFICIENT

0 DEGREES SWEEP

25 DEGREES SWEEP

53 DEGREES SWEEP

70 DEGREES SWEEP

FIGURE 3.)

RAE WING

70 DEGREE SWEEP, MACH 1.5, ALPHA = 0

PRESSURE COEFFICIENT MAP

RAE WING

NACA 64A010 Airfoil

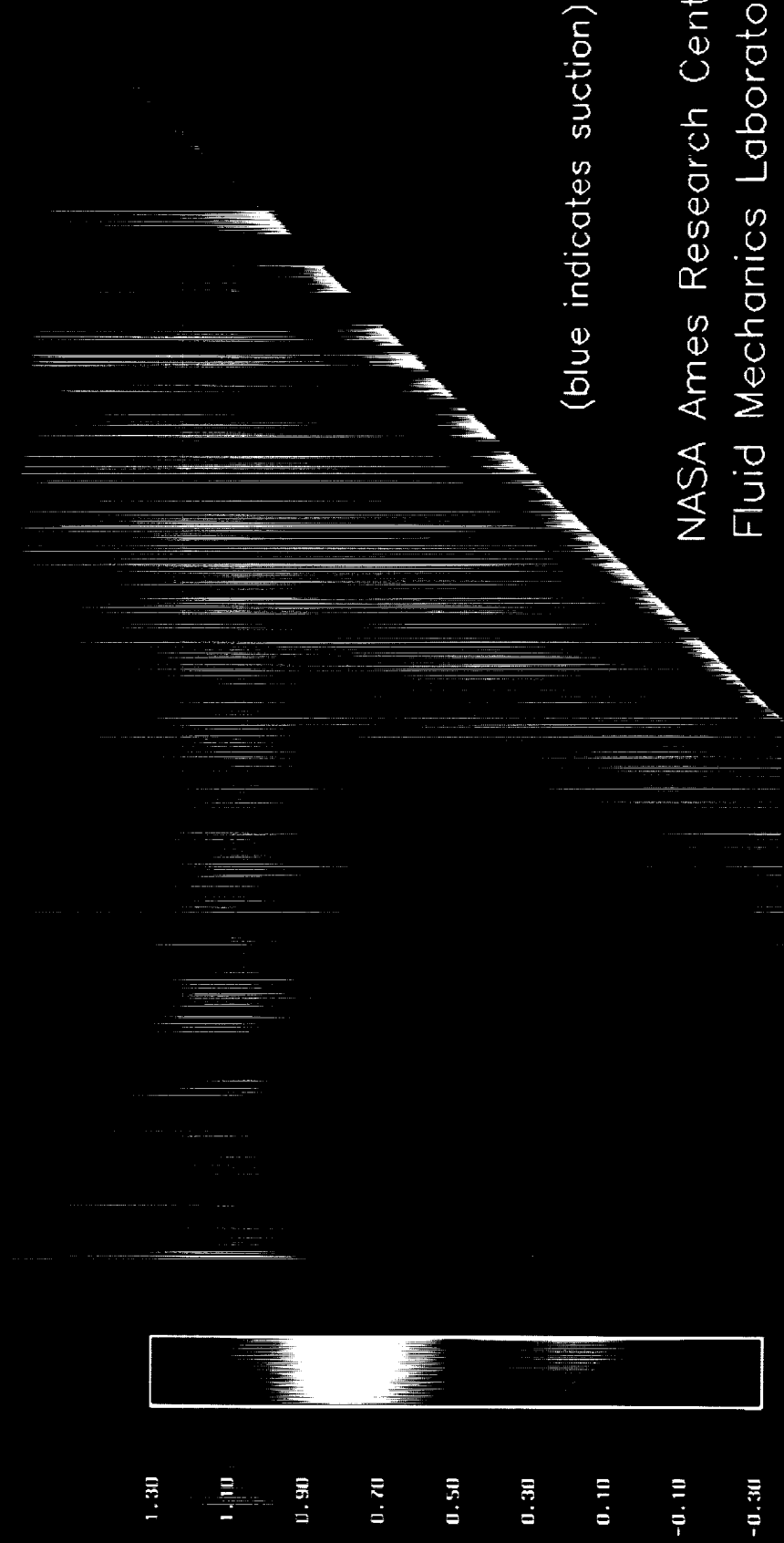Sweep = 70 degrees, Mach = 1.5, Alpha = 0

Pressure Coefficient Map

(blue indicates suction)

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1.30
1.10
0.90
0.70
0.50
0.30
0.10
-0.10
-0.30

FIGURE 4.)

RAE WING

70 DEGREE SWEEP, MACH 1.5, ALPHA = 0

MIDSPAN PRESSURE DISTRIBUTION

RAE WING

NACA 64A010 Airfoil

Pressure distribution at midspan
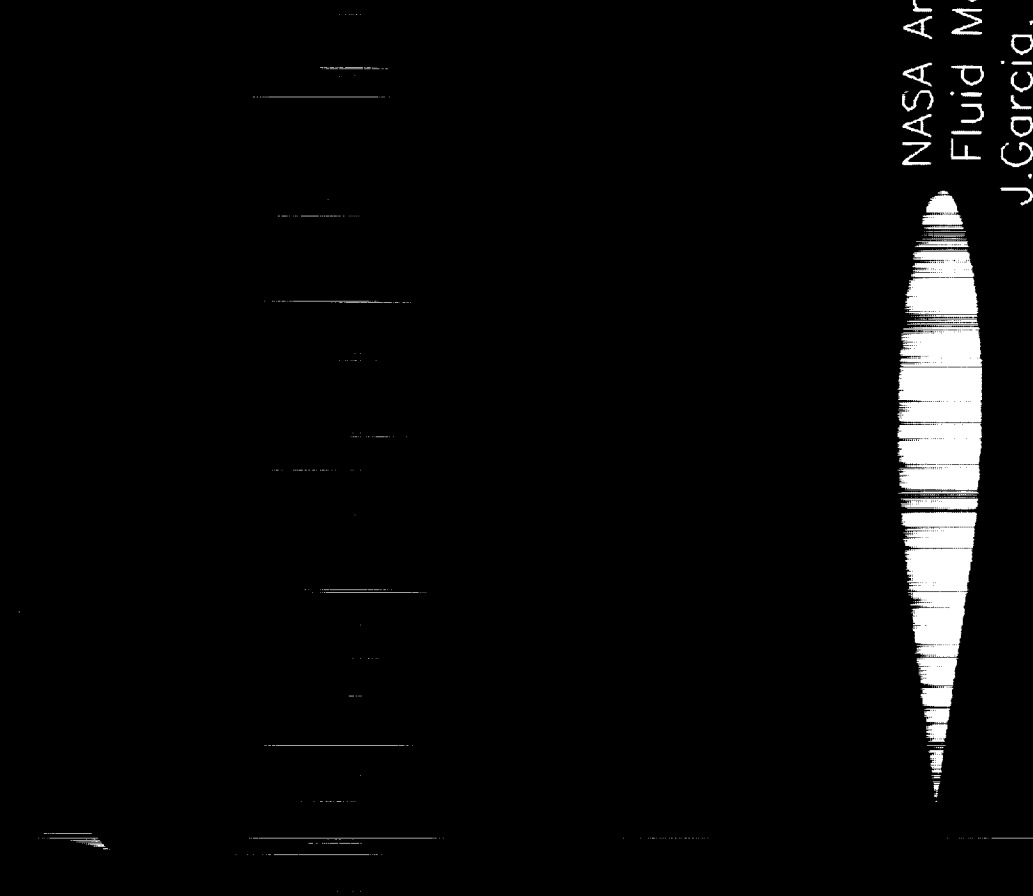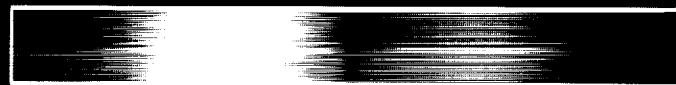
NASA Ames Research Center
Fluid Mechanics Laboratory
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APPENDIX A

TRANSITION AND TURBULENCE WORKSHOP

WORKING GROUP ASSIGNMENTS

ADVANCED ASYMPTOTICS - I

Group Leader: Philip Hall, University of Manchester, England

Andrew Bassom, University of Exeter, England
Nic Blackaby, College of William and Mary
Tom Bridges, University of Warwick, England
Stephen Cowley, University of Cambridge, England
Dominic Davis, University College London, England
James Denier, University of Manchester, England
J. S. B. Gajjar, Exeter University, England
Andrew Walton, University College London, England

ADVANCED ASYMPTOTICS - II

Group Leader: Manny Salas, NASA LaRC

Stanley Berger, University of California, Berkeley
Chet Grosch, Old Dominion University
Norman Malmuth, Rockwell International
Frank Smith, University College London, England

ADVANCED STABILITY

Group Leader: Mujeeb Malik, NASA LaRC

Ponnampalam Balakumar, High Technology Corporation
Marco Bettelini, Brown University
Chau-Lyan Chang, High Technology Corporation
Manhar Dhanak, Florida Atlantic University
Peter Duck, University of Manchester, England
Nabil El-Hady, A S & M
Ged Gasperas, Calspan Corporation
Glenn Lasseigne, Old Dominion University
Reda Mankbadi, NASA Lewis
Martin Simen, DLR, Germany

RECEPTIVITY

Group Leader: Michele Macaraeg, NASA LaRC

Thomas Buter, The Arizona State University
Meelan Choudhari, High Technology Corporation
Paul Hammerton, The University of Arizona
Edward Kerschen, The University of Arizona
Nay Lin, The Arizona State University
Lian Ng, A S &M

SIMULATION - I

Group Leader: Craig Streett, NASA LaRC

Keith Blodgett, University of Cincinnati
Gokhan Danabasoglu, University of Colorado
Ronald Joslin, NASA LaRC
Ray-Sing Lin, The Arizona State University
Helen Reed, The Arizona State University
Eileen Saiki, University of Colorado
Sonya Smith, University of Virginia
C. P. van Dam, University of California, Davis

SIMULATION - II

Group Leader: Tom Zang, NASA LaRC

Alvin Bayliss, Northwestern University
Surya Dinavahi, A S & M
Abdelkades Frendi, Vigyan Research Associates
Dan Henningson, Massachusetts Institute of Technology
Lucio Maestrello, NASA LaRC
Charles Pruett, National Research Council
Peter Schmid, Massachusetts Institute of Technology
Bart Singer, High Technology Corporation

SIMULATION - III

Group Leader: Gordon Erlebacher, ICASE

David Ashpis, NASA Lewis
Jeffrey Crouch, Naval Research Laboratory
Ferhat Hatay, University of Colorado
George Karniadakos, Princeton University
Dongshin Shin, Stanford University
Ananias Tomboulides, Princeton University
Paul Vijgen, High Technology Corporation

TURBULENCE MODELING

Group Leader: Charles Speziale, ICASE

Peter Bernard, University of Maryland
A. O. Demuren, Old Dominion University
Linda Kral, McDonnell Douglas Research Laboratories
Avi Lin, University of Pennsylvania
Siva Thangam, ICASE
Zhigang Yang, NASA Lewis

TURBULENCE THEORY

Group Leader: Tom Gatski, NASA LaRC

Ridha Abid, Vigyan, Inc.
Mark Glauser, Clarkson University
Tom Jackson, Old Dominion University and ICASE
Sutanu Sarkar, ICASE
Bhimsen Shivamoggi, University of Central Florida
D. P. Tselepidakis, University of Manchester, England

EXPERIMENT - I

Group Leader: Steve Wilkinson, NASA LaRC

Thomas Corke, Illinois Institute of Technology
Scott Kjelgaard, NASA LaRC
Yasuaki Kohama, Tohoku University
Steve Schneider, Purdue University

EXPERIMENT - II

Group Leader: Steve Robinson, NASA LaRC

Amy Alving, University of Minnesota
John Donovan, McDonnell Douglas Corporation
David Parekh, McDonnell Douglas Corporation
Richard Wlezien, Illinois Institute of Technology

APPENDIX B

TRANSITION AND TURBULENCE WORKSHOP

ELI RESHOTKO SYMPOSIUM AGENDA

Eli Reshotko Symposium

OMNI Hotel, Newport News, VA
July 28, 1991
(804) 874-6664, ext. 7173

AGENDA

7:45 - 8:15   Breakfast Buffet in the Upper Bistro - 1st floor

8:15 - 8:30   Registration - Jr. Ballroom 3, lower level

8:30 - 8:45   Openings Remarks - Amphitheater - lower level

8:45 - 9:15   Mark Morkovin, Professor Emeritus, Illinois Institute of
Technology
"Bypass Transition Research: Issues and Philosophy"

9:15 - 9:30   Dennis Bushnell, NASA LaRC
"Supersonic Laminar Flow Control"

9:30 - 9:45   Harold Rogler, United Research Corporation
"Using Computer Software and Algorithms to Detect and Correct
Wordiness"

9:45 - 10:00   Raymond Chin, Purdue University at Indianapolis
"Generating Orthogonal Polynomials for Exponent Weights on a
Finite Interval"

10:00 - 10:30   BREAK

10:30 - 11:00   Michael Gaster, University of Cambridge, England
"The Generation of Disturbances in a Boundary Layer by Wall
Perturbations: The Vibrating Ribbon Revisited Once More"

11:00 - 11:15   Mujeeb Malik, High Technology Corporation
"Effect of Mach Number on Instability Waves Generated from a
Localized Disturbance"

11:15 - 11:30   Marvin Goldstein, NASA Lewis Research Center
The Effect of Three-Dimensional Disturbances on Boundary Layers"

11:30 - 11:45   Reda Mankbadi, NASA Lewis Research Center
"The Preferred Spanwise Wavenumber in Subharmonic-Type
Transition"

11:45 - 1:00   LUNCH

1:00 - 1:30   Thorwald Herbert, Ohio State University
"Effect of Spanwise Non-Uniformities on Boundary Layer
Transition"

1:30 - 1:45   Ozden Turan, McMaster University, Canada
"The Turbulence Structure in an Eight-Degree Conical Diffuser"

1:45 - 2:15	Isaac Greber, Case Western Reserve University "Entrainment Rate for a Row of Turbulent Jets"
2:15 - 2:30	Helen Reed, Arizona State University "Stability of High Speed Flows"
2:30 - 3:00	BREAK
3:00 - 3:30	Norman Malmuth, Rockwell International Science Center "Inviscid Stability of Hypersonic Strong Interaction Flow Over a Flat Plate"
3:30 - 3:45	Thomas Winn, University of Maryland, College Park "Hypersonic Aircraft"
3:45 - 4:00	Jamal Masad, Virginia Polytechnic Institute and State University "The Influence of Imperfections on the Stability of Compressible Boundary Layers"
4:00 - 4:30	William Saric, Arizona State University "Thither Transition to Turbulence"
4:30 -	Eli Reshotko, Case Western Reserve University "Past Reminisces and Future Speculations"
7:30	Banquet - Jr. Ballroom - Rooms 2 and 3